Executive Summary

Purpose of the Study

Throughout the history of the Clean Air Act, questions have been raised as to whether the health and environmental benefits of air pollution control justify the costs incurred by industry, taxpayers, and consumers. For the most part, questions about the costs and benefits of individual regulatory standards continue to be addressed during the regulatory development process through Regulatory Impact Analyses (RIAs) and other analyses which evaluate regulatory costs, benefits, and such issues as scope, stringency, and timing. There has never been, however, any comprehensive, long-term, scientifically valid and reliable study which answered the broader question:

> "How do the overall health, welfare, ecological, and economic benefits of Clean Air Act programs compare to the costs of these programs?"

To address this void, Congress added to the 1990 Clean Air Act Amendments a requirement under section 812 that EPA conduct periodic, scientifically reviewed studies to assess the benefits and the costs of the Clean Air Act. Congress further required EPA to conduct the assessments to reflect central tendency, or "best estimate," assumptions rather than the conservative assumptions sometimes deemed appropriate for setting protective standards.

This report is the first in this ongoing series of Reports to Congress. By examining the benefits and costs of the 1970 and 1977 Amendments, this report addresses the question of the overall value of America's historical investment in cleaner air. The first Prospective Study, now in progress, will evaluate the benefits and costs of the 1990 Amendments.

Study Design

Estimates of the benefits and costs of the historical Clean Air Act are derived by examining the differences in economic, human health, and environmental outcomes under two alternative scenarios: a "control scenario" and a "no-control scenario." The control scenario reflects actual historical implementation of clean air programs and is based largely on historical data. The no-control scenario is a hypothetical scenario which reflects the assumption that no air pollution controls were established beyond those in place prior to enactment of the 1970 Amendments. Each of the two scenarios is evaluated by a sequence of economic, emissions, air quality, physical effect, economic valuation, and uncertainty models to measure the differences between the scenarios in economic, human health, and environmental outcomes. Details of this analytical sequence are presented in Chapter 1 and are summarized in Figure 1 of that chapter.

Summary of Results

Direct Costs

To comply with the Clean Air Act, businesses, consumers, and government entities all incurred higher costs for many goods and services. The costs of providing goods and services to the economy were higher primarily due to requirements to install, operate, and maintain pollution abatement equipment. In addition, costs were incurred to design and implement regulations, monitor and report regulatory compliance, and invest in research and development. Ultimately, these higher costs of production were borne by stockholders, business owners, consumers, and taxpayers.

Figure ES-1. Total Direct Compliance Costs of the CAA (in billions of inflation-adjusted dollars.)

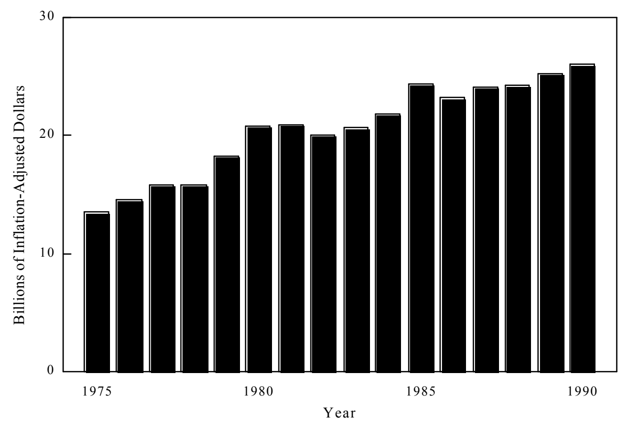
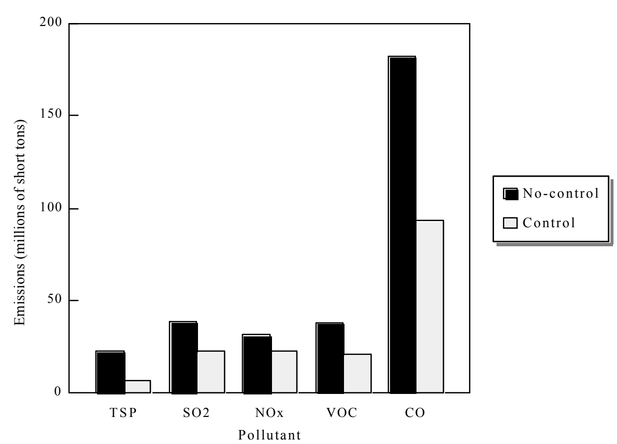


Figure ES-1 summarizes the historical data on Clean Air Act compliance costs by year, adjusted both for inflation and for the value of long-term investments in equipment. Further adjusting the direct costs incurred each year to reflect their equivalent worth in the year 1990, and then summing these annual results, yields an estimate of approximately $523 billion for the total value of 1970 to 1990 direct expenditures (see Appendix A for calculations).

Emissions

Emissions were substantially lower by 1990 under the control scenario than under the no-control scenario, as shown in Figure ES-2. Sulfur dioxide (SO_2) emissions were 40 percent lower, primarily due to utilities installing scrubbers and/or switching to lower sulfur fuels. Nitrogen oxides (NO_x) emissions were 30 percent lower by 1990, mostly because of the installation of catalytic converters on highway vehicles. Volatile organic compound (VOC) emissions were 45 percent lower and carbon monoxide (CO) emissions were 50 percent lower, also primarily due to motor vehicle controls.

Figure ES-2. 1990 Control and No-control Scenario Emissions (in millions of short tons).



For particulate matter, it is important to recognize the distinction between reductions in directly emitted particulate matter and reductions in ambient concentrations of particulate matter in the atmosphere. As discussed further in the next section, changes in particulate matter air quality depend both on changes in emissions of primary particles (i.e., air pollution which is already in solid particle form) and on changes in emissions of gaseous pollutants, such as sulfur dioxide and nitrogen oxides, which can be converted to particulate matter through chemical transformation in the atmosphere. Emissions of primary particulates were 75 percent lower under the control scenario by 1990 than under the no-control scenario. This substantial difference is primarily due to vigorous efforts in the 1970s to reduce visible emissions from utility and industrial smokestacks.

Lead (Pb) emissions for 1990 are reduced by about 99 percent from a no-control level of 237,000 tons to about 3,000 tons under the control scenario. [1] The vast majority of the difference in lead emissions under the two scenarios is attributable to reductions in the use of leaded gasoline.

Air Quality

The substantial reductions in air pollutant emissions achieved by the Clean Air Act translate into significantly improved air quality throughout the U.S. For sulfur dioxide, nitrogen oxides, and carbon monoxide, the improvements in air quality under the control scenario are proportional to the estimated reduction in emissions. This is because, for these pollutants, changes in ambient concentrations in a particular area are strongly related to changes in emissions in that area. While the differences in control and no-control scenario air quality for each of these pollutants vary from place to place because of local variability in emissions reductions, by 1990 the national average improvements in air quality for these pollutants were: 40 percent reduction in sulfur dioxide, 30 percent reduction in nitrogen oxides, and 50 percent reduction in carbon monoxide.

Ground-level ozone is formed by the chemical reaction of certain airborne pollutants in the presence of sunlight. Reductions in ground-level ozone are therefore achieved through reductions in emissions of its precursor pollutants, particularly volatile organic compounds (VOCs) and nitrogen oxides (NO_x).[2] The differences in ambient ozone concentrations estimated under the control scenario vary significantly from one location to another, primarily because of local differences in the relative proportion of VOCs and NO_x, weather conditions, and specific precursor emissions reductions. On a national average basis, ozone concentrations in 1990 are about 15 percent lower under the control scenario. For several reasons, this overall reduction in ozone is significantly less than the 30 percent reduction in precursor NO_x and 45 percent reduction in precursor VOCs. First, significant natural (i.e., biogenic) sources of VOCs limit the level of ozone reduction achieved by reductions in man-made (i.e., anthropogenic) VOCs. Second, current knowledge of atmospheric photochemistry suggests that ozone reductions will tend to be proportionally smaller than reductions in precursor emissions. Finally, the plume model system used to estimate changes in urban ozone for this study is incapable of handling long-range transport of ozone from upwind areas and multi-day pollution events in a realistic manner.

There are many pollutants which contribute to ambient concentrations of particulate matter. The relative contributions of these individual pollutant species to ambient particulate matter concentrations vary from one region of the country to the next, and from urban areas to rural areas. The most important particle species, from a human health standpoint, may be the fine particles which can be respired deep into the lungs. While some fine particles are directly emitted by sources, the most important fine particle species are formed in the atmosphere through chemical conversion of gaseous

[1] Results for lead are not shown in Figure ES-2 because the absolute levels of lead emissions are measured in thousands, not millions, of tons and will not be discernible on a graph of this scale.

[2] Ambient NO_x concentrations are driven by anthropogenic emissions whereas ambient VOCs result from both anthropogenic and biogenic sources (e.g., terpenes emitted by trees).

pollutants. These species are referred to as secondary particles. The three most important secondary particles are (1) sulfates, which derive primarily from sulfur dioxide emissions; (2) nitrates, which derive primarily from nitrogen oxides emissions; and (3) organic aerosols, which can be directly emitted or can form from volatile organic compound emissions. This highlights an important and unique feature of particulate matter as an ambient pollutant: more than any other pollutant, reductions in particulate matter are actually achieved through reductions in a wide variety of air pollutants. In other words, controlling particulate matter means controlling "air pollution" in a very broad sense. In the present analysis, reductions in sulfur dioxide, nitrogen oxides, volatile organic compounds, and directly-emitted primary particles achieved by the Clean Air Act result in a national average reduction in total ambient particulate matter of about 45 percent by 1990.

Reductions in sulfur dioxide and nitrogen oxides also translate into reductions in formation, transport, and deposition of secondarily formed acidic compounds such as sulfate and nitric acid. These are the principal pollutants responsible for acid precipitation, or "acid rain." Under the control scenario, sulfur and nitrogen deposition are significantly lower by 1990 than under the no-control scenario throughout the 31 eastern states covered by EPA's Regional Acid Deposition Model (RADM). Percentage decreases in sulfur deposition range up to more than 40 percent in the upper Great Lakes and Florida-Southeast Atlantic Coast areas, primarily because the no-control scenario projects significant increases in the use of high-sulfur fuels by utilities in the upper Great Lakes and Gulf Coast states. Nitrogen deposition is also significantly lower under the control scenario, with percentage decreases reaching levels of 25 percent or higher along the Eastern Seaboard, primarily due to higher projected emissions of motor vehicle nitrogen oxides under the no-control scenario.

Finally, decreases in ambient concentrations of light-scattering pollutants, such as sulfates and nitrates, are estimated to lead to perceptible improvements in visibility throughout the eastern states and southwestern urban areas modeled for this study.

Physical Effects

The lower ambient concentrations of sulfur dioxide, nitrogen oxides, particulate matter, carbon monoxide, ozone and lead under the control scenario yield a substantial variety of human health, welfare and ecological benefits. For a number of these benefit categories, quantitative functions are available from the scientific literature which allow estimation of the reduction in incidence of adverse effects. Examples of these categories include the human mortality and morbidity effects of a number of pollutants, the neurobehavioral effects among children caused by exposure to lead, visibility impairment, and effects on yields for some agricultural products.

A number of benefit categories, however, can not be quantified and/or monetized for a variety of reasons. In some cases, substantial scientific uncertainties prevail regarding the existence and magnitude of adverse effects (e.g., the contribution of ozone to air pollution-related mortality). In other cases, strong scientific evidence of an effect exists, but data are still too limited to support quantitative estimates of incidence reduction (e.g., changes in lung function associated with long-term exposure to ozone). Finally, there are effects for which there is sufficient information to estimate incidence reduction, but for which there are no available economic value measures; thus reductions in adverse effects cannot be expressed in monetary terms. Examples of this last category include pulmonary function decrements caused by acute exposures to ozone and reduced time to onset of angina pain caused by carbon monoxide exposure.

Table ES-1 provides a summary of the key differences in quantified human health outcomes

Table ES-1. Criteria Pollutant Health Benefits — Distributions of 1990 Incidences of Avoided Health Effects (in thousands of incidences reduced) for 48 State Population. [/1]

Endpoint	Pollutant(s)	Affected Population	Annual Effects Avoided[/2] (thousands)			Unit
			5th %ile	Mean	95th %ile	
Premature Mortality	PM-10 [/3]	30 and over	112	184	257	cases
Premature Mortality	Lead	all	7	22	54	cases
Chronic Bronchitis	PM-10	all	498	674	886	cases
Lost IQ Points	Lead	children	7,440	10,400	13,000	points
IQ less than 70	Lead	children	31	45	60	cases
Hypertension	Lead	men 20-74	9,740	12,600	15,600	cases
Coronary Heart Disease	Lead	40-74	0	22	64	cases
Atherothrombotic brain infarction	Lead	40-74	0	4	15	cases
Initial cerebrovascular accident	Lead	40-74	0	6	19	cases
Hospital Admissions						
All Respiratory	PM-10 & Ozone	all	75	89	103	cases
Chronic Obstructive Pulmonary Disease & Pneumonia	PM-10 & Ozone	over 65	52	62	72	cases
Ischemic Heart Disease	PM-10	over 65	7	19	31	cases
Congestive Heart Failure	PM-10 & CO	65 and over	28	39	50	cases
Other Respiratory-Related Ailments						
Shortness of breath, days	PM-10	children	14,800	68,000	133,000	days
Acute Bronchitis	PM-10	children	0	8,700	21,600	cases
Upper & Lower Respiratory Symptoms	PM-10	children	5,400	9,500	13,400	cases
Any of 19 Acute Symptoms	PM-10 & Ozone	18-65	15,400	130,000	244,000	cases
Asthma Attacks	PM-10 & Ozone	asthmatics	170	850	1,520	cases
Increase in Respiratory Illness	NO2	all	4,840	9,800	14,000	cases
Any Symptom	SO2	asthmatics	26	264	706	cases
Restricted Activity and Work Loss Days						
Minor Restricted Activity Days	PM-10 & Ozone	18-65	107,000	125,000	143,000	days
Work Loss Days	PM-10	18-65	19,400	22,600	25,600	days

[/1] The following additional human welfare effects were quantified directly in economic terms: household soiling damage, visibility impairment, decreased worker productivity, and agricultural yield changes.

[/2] The 5th and 95th percentile outcomes represent the lower and upper bounds, respectively, of the 90 percent credible interval for each effect as estimated by uncertainty modeling. The mean is the arithmetic average of all estimates derived by the uncertainty modeling. See Chapter 7 and Appendix I for details.

[/3] In this analysis, PM-10 is used as a proxy pollutant for all non-Lead (Pb) criteria pollutants which may contribute to premature mortality. See Chapter 5 and Appendix D for additional discussion.

under the control and no-control scenarios. Results are presented as thousands of cases avoided in 1990 due to control of the pollutants listed in the table and reflect reductions estimated for the entire U.S. population living in the 48 continental states. A range is presented along with the mean estimate for each effect, reflecting uncertainties in the underlying health effects literature.

Adverse human health effects of the Clean Air Act "criteria pollutants" sulfur dioxide, nitrogen oxides, ozone, particulate matter, carbon monoxide, and lead dominate the quantitative estimates in part because knowledge of physical consequences is greatest for these pollutants. The Clean Air Act yielded other benefits, however, which are important even though they are uncertain and/or difficult to quantify. These other benefit categories include (a) all benefits accruing from reductions in hazardous air pollutants (also referred to as air toxics), (b) reductions in damage to cultural resources, buildings, and other materials, (c) reductions in adverse effects on wetland, forest, and aquatic ecosystems, and (d) a variety of additional human health and welfare effects of criteria pollutants. A complete list of these nonmonetized effects is presented in Table ES-2.

In addition to controlling the six criteria pollutants, the 1970 and 1977 Clean Air Act Amendments led to reductions in ambient concentrations of a small number of hazardous air pollutants. Although they are not fully quantified in this report, control of these pollutants resulted both from regulatory standards set specifically to control hazardous air pollutants and from incidental reductions achieved through programs aimed at controlling criteria pollutants.

Existing scientific research suggests that reductions in both hazardous air pollutants and criteria pollutants yielded widespread improvements in the functioning and quality of aquatic and terrestrial ecosystems. In addition to any intrinsic value to be attributed to these ecological systems, human welfare is enhanced through improvements in a variety of ecological services. For example, protection of freshwater ecosystems achieved through reductions in deposition of acidic air pollutants may improve commercial and recreational fishing. Other potential ecological benefits of reduced acid deposition include improved wildlife viewing, maintenance of biodiversity, and nutrient cycling. Increased growth and productivity of U.S. forests may have resulted from reductions in ground-level ozone. More vigorous forest ecosystems in turn yield a variety of benefits, including increased timber production; improved forest aesthetics for people enjoying outdoor activities such as hunting, fishing, and camping; and improvements in ecological services such as nutrient cycling and temporary sequestration of global warming gases. These improvements in ecological structure and function have not been quantified in this assessment.

Table ES-2. Major Nonmonetized, Adverse Effects Reduced by the Clean Air Act.

Pollutant	Nonmonetized Adverse Effects
Particulate Matter	Changes in Pulmonary Function Other Chronic Respiratory Diseases Inflammation of the Lung Chronic Asthma and Bronchitis
Ozone	Changes in Pulmonary Function Increased Airway Responsiveness to Stimuli Centroacinar Fibrosis Inflammation of the Lung Immunological Changes Chronic Respiratory Diseases Extrapulmonary Effects (i.e., other organ systems) Forest and other Ecological Effects Materials Damage
Carbon Monoxide	Decreased Time to Onset of Angina Behavioral Effects Other Cardiovascular Effects Developmental Effects
Sulfur Dioxide	Respiratory Symptoms in Non-Asthmatics Hospital Admissions Agricultural Effects Materials Damage Ecological Effects
Nitrogen Oxides	Increased Airway Responsiveness to Stimuli Decreased Pulmonary Function Inflammation of the Lung Immunological Changes Eye Irritation Materials Damage Eutrophication (e.g., Chesapeake Bay) Acid Deposition
Lead	Cardiovascular Diseases Reproductive Effects in Women Other Neurobehavioral, Physiological Effects in Children Developmental Effects from Maternal Exposure, inc IQ Loss [/1] Ecological Effects
Air Toxics	All Human Health Effects Ecological Effects

[/1] IQ loss from direct, as opposed to maternal, exposure is quantified and monetized. See Tables ES-1 And ES-3.

Economic Valuation

Estimating the reduced incidence of physical effects provides a valuable measure of health benefits for individual endpoints. However, to compare or aggregate benefits across endpoints, the benefits must be monetized. Assigning a monetary value to avoided incidences of each effect permits a summation, in terms of dollars, of monetized benefits realized as a result of the Clean Air Act, and allows that summation to be compared to the cost of the Clean Air Act.

Table ES-3. Central Estimates of Economic Value per Unit of Avoided Effect (in 1990 dollars).

Endpoint	Pollutant	Valuation (mean est.)	
Mortality	PM-10 & Lead	$4,800,000	per case
Chronic Bronchitis	PM-10	$260,000	per case
IQ Changes			
Lost IQ Points	Lead	$3,000	per IQ point
IQ less than 70	Lead	$42,000	per case
Hypertension	Lead	$680	per case
Strokes /1	Lead	$200,000 $150,000	per case-males per case-females
Coronary Heart Disease	Lead	$52,000	per case
Hospital Admissions			
Ischemic Heart Disease	PM-10	$10,300	per case
Congestive Heart Failure	PM-10	$8,300	per case
COPD	PM-10 & Ozone	$8,100	per case
Pneumonia	PM-10 & Ozone	$7,900	per case
All Respiratory	PM-10 & Ozone	$6,100	per case
Respiratory Illness and Symptoms			
Acute Bronchitis	PM-10	$45	per case
Acute Asthma	PM-10 & Ozone	$32	per case
Acute Respiratory Symptoms	PM-10, Ozone, NO_2, SO_2	$18	per case
Upper Respiratory Symptoms	PM-10	$19	per case
Lower Respiratory Symptoms	PM-10	$12	per case
Shortness of Breath	PM-10	$5.30	per day
Work Loss Days	PM-10	$83	per day
Mild Restricted Activity Days	PM-10 & Ozone	$38	per day
Welfare Benefits			
Visibility	DeciView	$14	per unit change in DeciView
Household Soiling	PM-10	$2.50	per household per PM-10 change
Decreased Worker Productivity	Ozone	$1	/2
Agriculture (Net Surplus)	Ozone	Change in Economic Surplus	

/1 Strokes are comprised of atherothrombotic brain infarctions and cerebrovascular accidents; both are estimated to have the same monetary value.
/2 Decreased productivity valued as change in daily wages: $1 per worker per 10% decrease in ozone.

Before proceeding through this step, it is important to recognize the substantial controversies and uncertainties which pervade attempts to characterize adverse human health and ecological effects of pollution in dollar terms. To many, dollar-based estimates of the value of avoiding outcomes such as loss of human life, pain and suffering, or ecological degradation do not capture the full and true value to society as a whole of avoiding or reducing these effects. Adherents to this view tend to favor assessment procedures which (a) adopt the most technically defensible dollar-based valuation estimates for analytical purposes but (b) leave the moral dimensions of policy evaluation to those who must decide whether, and how, to use cost-benefit results in making public policy decisions. This is the paradigm adopted in the present study. Given the Congressional mandate to perform a cost-benefit study of the Clean Air Act, the Project Team has endeavored to apply widely-recognized, customary techniques of Applied Economics to perform this cost-benefit analysis. However, EPA believes there are social and personal values furthered by the Clean Air Act which have not been effectively captured by the dollar-based measures used in this study. Therefore, EPA strongly encourages readers to look beyond the dollar-based comparison of costs and benefits of the Clean Air Act and consider the broader value of the reductions in adverse health and environmental effects which have been achieved as well as any additional adverse consequences of regulation which may not be reflected in the cost estimates reported herein.

For this study, unit valuation estimates are derived from the economic literature and reported in dollars per case avoided for health effects and dollars per unit of avoided damage for human welfare effects. Similar to estimates of physical effects provided by health studies, each of the monetary values of benefits applied in this analysis can be expressed in terms of a mean value and a range around the mean estimate. This range reflects the uncertainty in the economic valuation literature associated with a given effect. These value ranges, and the approaches used to derive them, are described in Chapter 6 and Appendix I for each of the effects monetized in this study. The mean values of these ranges are shown in Table ES-3.

Monetized Benefits and Costs

The total monetized economic benefit attributable to the Clean Air Act is derived by applying the unit values (or ranges of values) to the stream of monetizable physical effects estimated for the 1970 to 1990 period. In developing these estimates, steps are taken to avoid double-counting of benefits. In addition, a computer simulation model is used to estimate ranges of plausible outcomes for the benefits estimates reflecting uncertainties in the physical effects and economic valuation literature (see Chapter 7 and Appendix I for details).

The economic benefit estimation model then generated a range of economic values for the differences in physical outcomes under the control and no-control scenarios for the target years of the benefits analysis: 1975, 1980, 1985, and 1990. Linear interpolation between these target years is used to estimate benefits in intervening years. These yearly results are then adjusted to their equivalent value in the year 1990 and summed to yield a range and mean estimate for the total monetized benefits of the Clean Air Act from 1970 to 1990. These results are summarized in Table ES-4.

Combining these benefits results with the cost estimates presented earlier yields the following analytical outcomes.

- The total monetized benefits of the Clean Air Act realized during the period from 1970 to 1990 range from 5.6 to 49.4 trillion dollars, with a central estimate of 22.2 trillion dollars.

- By comparison, the value of direct compliance expenditures over the same period equals approximately 0.5 trillion dollars.

- Subtracting costs from benefits results in net, direct, monetized benefits ranging from 5.1 to 48.9 trillion dollars, with a central estimate of 21.7 trillion dollars, for the 1970 to 1990 period.

Table ES-4. Total Monetized Benefits by Endpoint Category for 48 State Population for 1970 to 1990 Period (in billions of 1990 dollars).

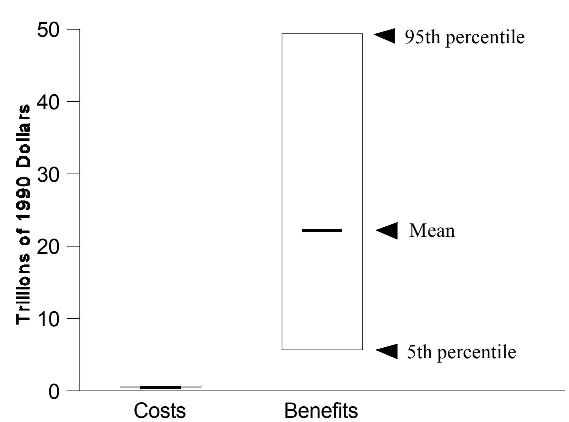
Endpoint	Pollutant(s)	Present Value		
		5th % ile	Mean	95th % ile
Mortality	PM-10	$2,369	$16,632	$40,597
Mortality	Lead	$121	$1,339	$3,910
Chronic Bronchitis	PM-10	$409	$3,313	$10,401
IQ (Lost IQ Pts. + Children w/ IQ<70)	Lead	$271	$399	$551
Hypertension	Lead	$77	$98	$120
Hospital Admissions	PM-10, Ozone, Lead, & CO	$27	$57	$120
Respiratory-Related Symptoms, Restricted Activity, & Decreased Productivity	PM-10, Ozone, NO2, & SO2	$123	$182	$261
Soiling Damage	PM-10	$6	$74	$192
Visibility	particulates	$38	$54	$71
Agriculture (Net Surplus)	Ozone	$11	$23	$35

- The lower bound of this range may go down and the upper bound may go up if analytical uncertainties associated with compliance costs, macroeconomic effects, emissions projections, and air quality modeling could be quantified and incorporated in the uncertainty analysis.

- The central estimate of 22.2 trillion dollars in benefits may be a significant underestimate due to the exclusion of large numbers of benefits from the monetized benefit estimate (e.g., all air toxics effects, ecosystem effects, numerous human health effects).

Figure ES-3 provides a graphical representation of the estimated range of total monetized benefits and compares this range to estimated direct compliance costs.

Figure ES-3. Total Direct Costs and Monetized Direct Benefits of the Clean Air Act, 1970 to 1990 (in trillions of 1990 dollars).



Clearly, even the lower bound estimate of monetized benefits substantially exceeds the costs of the historical Clean Air Act. As shown by the yearly data presented in Chapter 7, monetized benefits consistently and substantially exceeded costs throughout the 1970 to 1990 period.

Alternative Results

The primary results of this analysis, including aggregate cost and benefit estimates which reflect many elements of the uncertainty associated with them, are presented above. However, some additional analysis is required to address an important issue raised by the EPA Science Advisory Board Council on Clean Air Act Compliance Analysis (a.k.a. Council) charged with reviewing the present study. Specifically, the Council believes it is appropriate to also display alternative premature mortality results based on an approach which estimates, and assigns a value to, the loss of life-years (i.e., the reduction in years of remaining life expectancy) resulting from the pollution exposure. EPA believes, however, that the simplifying assumptions which must be adopted to implement a life-years lost approach render its results less reliable, even for the purposes of economic efficiency analysis, than a value of statistical life approach. In addition, EPA is concerned about any analytical methodology which may be interpreted to justify conferring less environmental protection on particular individuals or groups of individuals (e.g., the elderly and/or sick). EPA therefore prefers at this time to continue with its current practice of assigning the same economic value to incidences of premature mortality regardless of the age and health status of those affected, and the primary results presented above reflect this view. Nevertheless, complete alternative results based on a value of statistical life-years lost (VSLY) approach are presented in Chapter 7 and Appendix I and are summarized below.

Table ES-5 summarizes and compares the results of the mortality benefits estimates based on the value of statistical life (VSL) and VSLY approaches. Estimated 1970 to 1990 benefits from PM-related mortality alone and total mortality (i.e., PM plus Lead) benefits are reported, along with total compliance costs for the same period. Adding the VSLY-based mortality benefits estimates to the non-mortality benefits estimates from Table ES-4 yields the following results for the overall analysis.

Table ES-5. Alternative Mortality Benefits Mean Estimates for 1970 to 1990 (in trillions of 1990 dollars) Compared to Total 1970 to 1990 Compliance Costs.

	Mortality Benefits	
Benefit Estimation Method	PM	PM+Pb
Statistical life method ($4.8M/case)	16.6	18.0
Life-years lost method ($293,000/year)	9.1	10.1
Total compliance cost	---	0.5

- Alternate Result: The total monetized benefits of the Clean Air Act realized during the period from 1970 to 1990 range from 4.8 to 28.7 trillion dollars, with a central estimate of 14.3 trillion dollars.

- Alternate Result: Subtracting costs from benefits results in net, direct, monetized benefits ranging from 4.3 to 28.2 trillion dollars, with a central estimate of 13.7 trillion dollars, for the 1970 to 1990 period.

The results indicate that the choice of valuation methodology significantly affects the estimated monetized value of historical reductions in air pollution-related premature mortality. However, the downward adjustment which would result from applying a VSLY approach in lieu of a VSL approach does not change the basic outcome of this study, viz. the estimated monetized benefits of the historical Clean Air Act substantially exceed the estimated historical costs of compliance.

Conclusions and Future Directions

First and foremost, these results indicate that the benefits of the Clean Air Act and associated control programs substantially exceeded costs. Even considering the large number of important uncertainties permeating each step of the analysis, it is extremely unlikely that the converse could be true.

A second important implication of this study is that a large proportion of the monetized benefits of the historical Clean Air Act derive from reducing two pollutants: lead and particulate matter [3] (see Table ES-4). Some may argue that, while programs to control these two pollutants may have been worthwhile, many other historical Clean Air Act programs would not pass a benefit-cost test when considered in isolation. While this may or may not be true, this analysis provides no evidence to support or reject such conjectures. On the cost side, the historical expenditure data used in this analysis are not structured in ways which allow attribution of control costs to specific programs or standards. On the benefit side, most control programs yielded a variety of benefits, many of which included reductions in other pollutants such as ambient particulate matter. For example, new source performance standards for sulfur dioxide emissions from coal-fired utility plants yielded benefits beyond those associated with reducing exposures to gaseous sulfur dioxide. The reductions in sulfur dioxide emissions also led to reductions in ambient fine particle sulfates, yielding human health, ecological, and visibility benefits.

This retrospective study highlights important areas of uncertainty associated with many of the monetized benefits included in the quantitative analysis and lists benefit categories which could not be quantified or monetized given the current state of the science. Additional research in these areas may reduce critical uncertainties and/or improve the comprehensiveness of future assessments. Particularly important areas where further research might reduce critical uncertainties include particulate matter-related mortality incidence, valuation of premature mortality, and valuation of particulate-related chronic bronchitis. Additional research on hazardous air pollutants and on air pollution-related changes in ecosystem structure and function might help improve the comprehensiveness of future benefit studies. (See Appendix J for further discussion.)

Finally, the results of this retrospective study provide useful lessons with respect to the value and the limitations of cost-benefit analysis as a tool for evaluating environmental programs. Cost-benefit analysis can provide a valuable framework for organizing and evaluating information on the effects of environmental programs. When used properly, cost-benefit analysis can help illuminate important effects of changes in policy and can help set priorities for closing information gaps and reducing uncertainty. Such proper use, however, requires that sufficient levels of time and resources be provided to permit careful, thorough, and technically and scientifically sound data-gathering and analysis. When cost-benefit analyses are presented without effective characterization of the uncertainties associated with the results, cost-benefit studies can be used in highly misleading and

[3] Ambient particulate matter results from emissions of a wide array of precursor pollutants, including sulfur dioxide, nitrogen oxides, and organic compounds.

damaging ways. Given the substantial uncertainties which permeate cost-benefit assessment of environmental programs, as demonstrated by the broad range of estimated benefits presented in this study, cost-benefit analysis is best used to inform, but not dictate, decisions related to environmental protection policies, programs, and research.

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